METHOD AND SYSTEM TO MEASURE CHARACTERISTICS OF A FILM DISPOSED ON A SUBSTRATE

BACKGROUND OF THE INVENTION

[0001] The field of invention relates generally to imprint lithography. More particularly, the present invention is directed measuring characteristics of a films patterned employing imprint lithography processes.

[0002] Micro-fabrication involves the fabrication of very small structures, e.g., having features on the order of micro-meters or smaller. One area in which micro-fabrication has had a sizeable impact is in the processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, micro-fabrication becomes increasingly important. Micro-fabrication provides greater process control while allowing increased reduction of the minimum feature dimension of the structures formed. Other areas of development in which micro-fabrication has been employed include biotechnology, optical technology, mechanical systems and the like.

[0003] Exemplary micro-fabrication technique are disclosed in United States patent number 6,334,960 to Willson et al. and by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, *Nature*, Col. 417, pp. 835-837, June 2002, which is referred to as a laser assisted direct imprinting (LADI) process. Both of these processes involve the use of forming a layer on a substrate by embossing a flowable material with a mold and subsequently solidifying the flowable material to form a patterned layer.

[0004] As a result of the small size of the features produced by micro-fabrication techniques, process diagnostics become increasingly important to determine the characteristics of films during processing and after processing. Many prior art process control and diagnostic techniques to facilitate determination of film characteristics have been employed in standard semiconductor processing operations. However, many of the existing process control and diagnostic techniques are not suitable for use with the embossing technique employed during micro-fabrication.

[0005] Thus, a need exists for providing improved process and diagnostic techniques for use with micro-fabrication processes, such as imprint lithography.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to providing a method and system to measure characteristics of a film disposed on a substrate. The method includes identifying a plurality of processing regions on the film; measuring characteristics of a subset of the plurality of processing regions, defining measured characteristics; determining a variation of one of the measured characteristics; and associating a cause of the variations based upon a comparison of the one of the measured characteristics to measured characteristics associated with the remaining processing regions of the subset. The system carries out the aforementioned method. These and other embodiments are discussed more fully below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a perspective view of a lithographic system in accordance with the present invention;

[0008] Fig. 2 is a simplified elevation view of a lithographic system shown in Fig. 1;

[0009] Fig. 3 is a simplified representation of material from which an imprinting layer, shown in Fig. 2, is comprised before being polymerized and cross-linked;

[0010] Fig. 4 is a simplified representation of cross-linked polymer material into which the material shown in Fig. 3 is transformed after being subjected to radiation;

[0011] Fig. 5 is a simplified elevation view of a mold spaced-apart from the imprinting layer, shown in Fig. 1, after patterning of the imprinting layer;

[0012] Fig. 6 is a simplified elevation view of an additional imprinting layer positioned atop of the substrate, shown in Fig. 5, after the pattern in the first imprinting layer is transferred therein;

[0013] Fig. 7 is a top down view of the substrate shown in Figs. 1 and 2;

[0014] Fig. 8 is a plan view of a sensing system in accordance with the present invention;

[0015] Fig. 9 is a detailed perspective view of an imprint head shown in Fig. 1;

[0016] Fig. 10 is a detailed cross-sectional view of a substrate, having a mold thereon, attached to a chucking system, shown in Fig. 1;

[0017] Fig. 11 is an exploded perspective view of the imprint head shown in Fig. 9;

[0018] Fig. 12 is a graph showing the mapping of reflected radiation, sensed by the sensing system shown in Fig. 8, in a frequency domain in accordance with the present invention; and

[0019] Fig. 13 is a flow chart showing a process for measuring characteristics of a film in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0020] Fig. 1 depicts a lithographic system 10 in accordance with one embodiment of the present invention that includes a pair of spaced-apart bridge supports 12 having a bridge 14 and a stage support 16 extending therebetween. Bridge 14 and stage support 16 are spaced-apart. Coupled to bridge 14 is an imprint head 18, which extends from bridge 14 toward stage support 16 and provides movement along the Z-axis. Disposed upon stage support 16 to face imprint head 18 is a motion stage, referred to as a substrate support stack 20. Substrate support stack 20 is configured to move with respect to stage support 16 along X- and Y-axes. It should be understood that imprint head 18 may provide movement along the X- and Y-axes, as well as the Z-axis, and motion stage 20 may provide movement in the Z-axis, as well as the X- and Y-axes. An exemplary substrate support stack 20 is disclosed in United States patent application number 10/194,414, filed July 11, 2002, entitled "Step and Repeat Imprint Lithography Systems," assigned to the assignee of the present invention, and which is incorporated by reference herein in its entirety. A radiation source 22 is coupled to lithographic system 10 to impinge actinic radiation upon substrate support stack 20. As shown, radiation source 22 is coupled to bridge 14 and includes a power generator 24 connected to radiation source 22. Operation of lithographic system 10 is typically controlled by a processor 26 that is in data communication therewith.

[0021] Referring to both Figs. 1 and 2, included in imprint head 18, is a chuck 28 to which a template 30 having a mold 32 thereon is mounted. An imprint head 18 and chuck 28 is disclosed in United States patent

application number 10/293,224, entitled "A Chucking System for Modulating Shapes of Substrates" filed November 13, 2002, which is assigned to the assignee of the present invention and incorporated by reference herein, as well as United States patent application number 10/316,963, entitled "A Method for Modulating Shapes of Substrates" filed December 11, 2002, which is assigned to the assignee of the present invention and incorporated by reference herein. Mold 32 includes a plurality of features defined by a plurality of spaced-apart recessions 34 and protrusions 36. The plurality of features defines an original pattern that forms the basis of a pattern that is to be transferred into a wafer 38 positioned on motion stage 20. To that end, imprint head 18 and/or motion stage 20 may vary a distance "d" between mold 32 and wafer 38. In this manner, the features on mold 32 may be imprinted into a flowable region of wafer 38, discussed more fully below. Radiation source 22 is located so that mold 32 is positioned between radiation source 22 and wafer 38. As a result, mold 32 is fabricated from a material that allows it to be substantially transparent to the radiation produced by radiation source 22.

[0022] Referring to both Figs. 2 and 3, a flowable region, such as an imprinting layer 40, is disposed on a portion of a surface 42 that presents a substantially planar profile. A flowable region may be formed using any known technique, such as a hot embossing process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein, or a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, *Nature*, Col. 417,

pp. 835-837, June 2002. In the present embodiment, however, a flowable region consists of imprinting layer 40 being deposited as a plurality of spaced-apart discrete beads 44 of a material 46 on wafer 38, discussed more fully below. An exemplary system for depositing beads 44 is disclosed in United States patent application number 10/191,749, filed July 9, 2002, entitled "System and Method for Dispensing Liquids," and which is assigned to the assignee of the present invention, and which is incorporated by reference in its entirety herein. Imprinting layer 40 is formed from material 46 that may be selectively polymerized and cross-linked to record the original pattern therein, defining a recorded pattern. An exemplary composition for material 46 is disclosed in Untied States patent application number 10/463,396, filed June 16, 2003 and entitled "Method to Reduce Adhesion Between a Conformable Region and a Pattern of a Mold," which is incorporated by reference in its entirety herein. Material 46 is shown in Fig. 4 as being cross-linked at points 48, forming a cross-linked polymer material 50.

[0023] Referring to Figs. 2, 3 and 5, the pattern recorded in imprinting layer 40 is produced, in part, by mechanical contact with mold 32. To that end, distance "d" is reduced to allow imprinting beads 44 to come into mechanical contact with mold 32, spreading beads 44 so as to form imprinting layer 40 with a contiguous formation of material 46 over surface 42. In one embodiment, distance "d" is reduced to allow sub-portions 52 of imprinting layer 40 to ingress into and fill recessions 34.

[0024] To facilitate filling of recessions 34, material 46 is provided with the requisite properties to

completely fill recessions 34, while covering surface 42 with a contiguous formation of material 46. In the present embodiment, sub-portions 54 of imprinting layer 40 in superimposition with protrusions 36 remain after the desired, usually minimum, distance "d", has been reached, leaving sub-portions 52 with a thickness t_1, and sub-portions 54 with a thickness t_2. Thicknesses "t_1" and "t_2" may be any thickness desired, dependent upon the application.

[0025] Referring to Figs. 2, 3 and 4, after a desired distance "d" has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 46, forming cross-linked polymer material 50. As a result, the composition of imprinting layer 40 transforms from material 46 to cross-linked polymer material 50, which is a solid. Specifically, cross-linked polymer material 50 is solidified to provide side 56 of imprinting layer 40 with a shape conforming to a shape of a surface 58 of mold 32, shown more clearly in Fig. 5. After imprinting layer 40 is transformed to consist of cross-linked polymer material 50, shown in Fig. 4, imprint head 18, shown in Fig. 2, is moved to increase distance "d" so that mold 32 and imprinting layer 40 are spaced-apart.

[0026] Referring to Fig. 5, additional processing may be employed to complete the patterning of wafer 38. For example, wafer 38 and imprinting layer 40 may be etched to transfer the pattern of imprinting layer 40 into wafer 38, providing a patterned surface 60, shown in Fig. 6. To facilitate etching, the material from which imprinting layer 40 is formed may be varied to define a relative etch rate with respect to wafer 38, as desired. The

relative etch rate of imprinting layer 40 to wafer 38 may be in a range of about 1.5:1 to about 100:1.

[0027] Referring to Figs. 7 and 8, typically the entire wafer 38 is patterned employing a step-and-repeat process. The step-and-repeat processes includes defining a plurality of regions, shown as, a-l, on wafer 38 in which the original pattern on mold 32 will be recorded. The original pattern on mold 32 may be coextensive with the entire surface of mold 32, or simply located to a sub-portion thereof. The present invention will be discussed with respect to the original pattern being coextensive with the surface of mold 32 that faces wafer 38. Proper execution of a step-and-repeat process may include proper alignment of mold 32 with each of regions a-l. To that end, mold 32 includes alignment marks (not shown). One or more of regions a-l includes fiducial marks (not shown). By ensuring that alignment marks (not shown) are properly aligned with fiducial marks (not shown), proper alignment of mold 32 with one of regions a-l in superimposition therewith is ensured. To that end, sensing device 62, discussed more fully below, may be employed. In this manner, mold 32 is sequentially contacted with each of processing regions a-l to record a pattern thereon.

[0028] Sensing device 62 may also be employed to facilitate process diagnostics. To that end, sensing device 62 includes a light source 64 and an optical train 66 to focus light upon wafer 38. Sensing device 62 is configured to focus alignment radiation reflected from regions a-l onto a single focal plane, P, wherein an optical sensor 68 may be positioned. As a result, optical train 66 may be configured to provide wavelength-dependent focal lengths, should it be desired and

differing wavelengths of light employed. Light may be produced in any manner known in the art. For example, a single broadband source of light, shown as a light 70, may produce wavelengths that impinge upon optical train 66. Optical band-pass filters (not shown) may be disposed between the broadband source and the alignment marks (not shown).

[0029] Alternatively, a plurality of sources of light (not shown) may be employed, each one of which produces distinct wavelengths of light. Light 70 is focused by optical train 66 to impinge upon regions a-l at one or more regions, shown as region R_1 and region R_2. Light reflects from regions R_1 and R_2, shown as a reflected light 72, and is collected by a collector lens 74. Collector lens 74 focuses all wavelengths of reflected light 72 onto plane P so that optical sensor 68 detects reflected light 72. The reflected light contains information concerning characteristics of imprinting layer 40 using well known techniques. For example, characteristics, such as, film thickness, pattern quality, pattern alignment, pattern critical dimension variation and the like may be obtained by light sensed by sensor 68. The information sensed by sensor 68 is transmitted to processor 26 that quantizes the same to create measurement quantizations. Processor 26 may then compare information received from sensor 68 to *a priori* information contained in a look up table, for example in memory 106, to determine whether anomalies are present in imprinting layer 40 of regions a-l.

[0030] Referring to Figs. 1 and 7, were an anomaly found in the pattern generated in a processing region a-l, the step-and-repeat imprinting process is found to facilitate determining a source of the anomaly. For

example, were it found that a substantially similar anomaly was found in each of processing regions a-l, it could be deduced that imprint head 18 was the cause of the anomaly. To determine which subsystem of imprint head 18 contributed to, or caused, the anomaly, the subsystems could be systematically replaced.

[0031] For example, referring to Figs. 9 and 10, imprint head 18 includes many subsystems, such as head housing 76 to which template 30 is coupled via a chucking system 80 that includes chuck body 28. Specifically, template 30 includes opposed surfaces 84 and 86 and a periphery surface 88 extending therebetween. Surface 86 faces chucking system 80, and mold 32 extends from surface 84. To ensure that fluid from beads 44, shown in Fig. 2, do not spread beyond the area of mold 32, surface 58 of mold 32 is spaced-apart from surface 84 of template 30 a distance on the order of micron, e.g., 15 microns. A calibration system 90 is coupled to imprint head housing 76, and chuck body 28 couples template 30 to calibration system 90 vis-à-vis a flexure system 92. Calibration system 90 facilitates proper orientation alignment between template 30 and wafer 38, shown in Fig. 2, thereby achieving a substantially uniform gap distance, "d", therebetween.

[0032] Referring to both Figs. 9 and 11, calibration system 90 includes a plurality of actuators 94, 96 and 98 and a base plate 100. Specifically, actuators 94, 96 and 98 are connected between housing 76 and base plate 100. Flexure system 92 includes flexure springs 102 and flexure ring 104. Flexure ring 104 is coupled between base plate 100 and flexure springs 102. Motion of actuators 94, 96 and 98 orientates flexure ring 104 that may allow for a coarse calibration of flexure springs 102

and, therefore, chuck body 28 and template 30. Actuators 94, 96 and 98 also facilitate translation of flexure ring 104 to the Z-axis. Flexure springs 102 include a plurality of linear springs that facilitate gimbal-like motion in the X-Y plane so that proper orientation alignment may be achieved between wafer 38 and template 30, shown in Fig. 2.

[0033] Referring to Figs. 1, 10 and 11, to determine whether mold 32 attributed to an anomaly, template 30 would be replaced. Were the anomaly absent, then it could be concluded that mold 32 was the source of the anomaly. Were the anomaly still present, another subsystem of imprint head 18 could be replaced, such as, flexure springs 102. Were the anomaly found to be absent in patterns of other regions a-l, and then it could be concluded that flexure springs 102 were the source. Were the anomaly still present, the other subsystems could be replaced, such as chuck body 28, actuators 94, 96, and 98, flexure ring 104 and the like.

[0034] Were it observed that the anomaly appeared in only one of processing regions, then it could be deduced that substrate support stack 20 was the cause of the anomaly. As discussed above with respect to imprint head 18, the subsystems of substrate support stack 20 may be individually replaced to identify the subsystem attributing to the anomaly.

[0035] It should also be understood, however, that anomalies and their sources may be determined without the use of Step-and-Repeat imprinting, e.g., with whole wafer patterning techniques. To that end, batches of substrates are examined during processing to determine whether anomalies are present on successive substrates. Were it found that a substantially similar anomaly was

found in the same region, or a similar anomaly in differing regions, on successive wafers 38, it could be deduced that mold 32 or chuck 28 was the cause of the defect. This could be verified by replacing mold 32. Were the anomaly still present, it could be concluded that the cause of the anomaly was chuck 28. Were the anomaly found not to repeat upon replacement of mold 32, it could be concluded that mold 32 was the cause of the anomaly. Were it observed that the anomaly appeared on a limited number or one of wafers 38, then it could be deduced that wafer 38 was the cause of the anomaly.

[0036] For example, the anomaly could be a film thickness variation. To that end, any one of a number of film thickness measurements can be employed, such as ellipsometry, scatterometety, broad-band spectrometry and the like. An exemplary technique for measuring film thickness is based on Fast Fourier Transform (FFT) of reflective radiation obtained from a broad-band spectrometer, which is disclosed in United States patent application number 09/920,341 entitled "Methods For High-Precision Gap Orientation Sensing Between a Transparent Template and Substrate For Imprint Lithography", which is incorporated by reference herein in its entirety. For multi-layer films, the technique may provide an average thickness of each thin film and its thickness variations by measuring at a predetermined number of sub-portions in one of processing regions a-l, e.g., 1,000 sub-portions. Employing FFT thickness measurement techniques, reflective radiation is digitized/quantized and a wave number obtained. The quantized data is then mapped into the frequency domain processing the same employing an FFT algorithm. In the frequency domain, one or more peaks, shown in Fig. 12 as p_1 and p_2, are obtained, one of which

may correspond to the film thickness at one of the sub-portions of one of processing regions a-l. For a clearly defined single peak, for example, p_1, the film thickness (t) may be a function of the frequency around which peak p_1 is centered. This may be derived or determined from *a priori* information.

[0037] For example, after obtaining film thickness measurements at several or all of the sub-portions, a mean value is derived from these thickness measurements. Thereafter, each of the film thickness measurements are compared to the mean value. If any one of the thickness measurements vary from the mean more than a predetermined threshold it may be determined that an anomaly with respect to the film thickness measurement in associated processing region a-l is present. Furthermore, the location of the anomaly within the processing region may be ascertained. The actual value of the threshold may be any desired and is typically dependent upon several factors, such as the design tolerance of the pattern, the thickness of the film and the like. Alternatively, it has been found to determine anomalies as a variation from a standard deviation from the mean value. To that end, the standard deviation, either first, second, third standard deviation and the like, from the mean is compared with a predetermined threshold. From the foregoing the film thickness in each of the processing regions a-l may be determined, as well as whether a film thickness anomaly is present.

[0038] Referring to Figs. 1 and 13, in operation, a plurality of processing regions is identified at step 200. At step 202 the characteristics of a subset of the plurality of processing regions are measured. The subset may include all of the processing regions a-l.

Determined, at step 204 are a variation of one or more of the measured characteristics, using one or more of the measurement techniques mentioned above. In the present example, assume an anomaly was found in processing region b. At step 206, a cause of the variation in processing region b is determined based upon a comparison with measured characteristics associated with processing regions a and c-l. To facilitate the aforementioned operation, processor 26 is coupled to a memory 106 that stores code to be operated on by processor 26. The code includes a first subroutine to control the sensing device 62, shown in Fig. 8, to impinge optical radiation on the plurality of processing regions a-l and detect optical radiation reflected therefrom. A second subroutine is included that controls the operations of the sensing device to obtain a predetermined number of measurements in the one of said plurality of processing regions a-l and quantizing the predetermined number of measurements to obtain a mean value, with the first subroutine determining the variation by comparing mean value with a predetermined threshold, which may be established as desired and/or based upon the application.

[0039] The embodiments of the present invention described above are exemplary. Although the invention has been described with respect to measuring film thickness anomalies, other anomalies may be determined. For example, distortions in the pattern may formed in imprinting layer may be sensed and the cause of the same determined employing the present invention. As a result, the system may be employed to detect anomalies in critical dimension variations of the pattern features, as well as, errors in field-to-field and/or layer-to-layer alignment. With such information adaptive control may be

employed to correct/compensate for such anomalies. These measurements may be made either *in-situ* or post processes. Furthermore, the invention has been discussed with respect to being placed upon an imprint lithography machine. However, the invention may be performed by a separate machine and apart from the imprint lithography process.

[0040] As a result, many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. Therefore, the scope of the invention should not be limited by the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.